

FINAL REPORT

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Final Report

During the period of this Cooperative Agreement, MIT developed advanced methods for applying silicon microstructures for the precision assembly of foil x-ray optics in support of the *Constellation-X* Spectroscopy X-ray Telescope (SXT) development effort at Goddard Space Flight Center (GSFC). MIT developed improved methods for fabricating and characterizing the precision silicon micro-combs. MIT also developed and characterized assembly tools and several types of metrology tools in order to characterize and reduce the errors associated with precision assembly of foil optics. Results of this effort were published and presented to the scientific community and the GSFC SXT team (see below).

Publications:

- “High precision assembly and metrology of x-ray foil optics,” O. Mongrard, N. Butler, C.G. Chen, R.K. Heilmann, P.T. Konkola, M. McGuirk, G. Monnelly, G.S. Pati, G.R. Ricker, M.L. Schattenburg and L. Cohen, *Proceedings of the Sixteenth Annual Meeting of the American Society for Precision Engineering* (American Society for Precision Engineering, Raleigh, NC), 40-43 (2001).
- “Novel methods for shaping thin-foil optics for x-ray astronomy,” R.K. Heilmann, G.P. Monnelly, O. Mongrard, N. Butler, C.G. Chen, L.M. Cohen, C.C. Cook, L.M. Goldman, P.T. Konkola, M. McGuirk, G.R. Ricker and M.L. Schattenburg, *Proc. SPIE 4496, X-ray Optics for Astronomy: Telescopes, Multilayers, Spectrometers and Missions*, eds. P. Gorenstein and R.B. Hoover, 62-72 (2002).

Presentations:

- “X-ray reflection grating update,” M.L. Schattenburg, *Constellation X-ray Mission Facility Science Team Meeting*, Cambridge, Massachusetts, May

4, 2001.

- “Novel methods for shaping thin-foil optics for x-ray astronomy,” R.K. Heilmann, G.P. Monnelly, O. Mongrard, N. Butler, C.G. Chen, L.M. Cohen, C.C. Cook, L.M. Goldman, P.T. Konkola, M. McGuirk, G.R. Ricker and M.L. Schattenburg, presented at the *SPIE Conference on X-ray Optics for Astronomy: Telescopes, Multilayers, Spectrometers and Missions*, San Diego, California, July 30, 2001 (paper 4496-06).
- “Segmented x-ray mirror for the Constellation-X Spectroscopy X-ray Telescope,” R. Petre, L.M. Cohen, D.A. Content, T.T. Saha, M.L. Schattenburg, J. Stewart and W.W. Zhang, *SPIE Conference on X-ray Optics for Astronomy: Telescopes, Multilayers, Spectrometers and Missions*, San Diego, California, July 30, 2001 (paper 4496-10).
- “Wavefront sensors for x-ray and EUV optics fabrication,” M. McGuirk, G.P. Monnelly, M.L. Schattenburg and C.R. Canizares, *SPIE Conference on X-ray Optics for Astronomy: Telescopes, Multilayers, Spectrometers and Missions*, San Diego, California, July 30, 2001 (paper 4496-12).
- “Alignment combs - status review and outlook,” R.K. Heilmann, G.P. Monnelly, D. Breslau, N. Butler, C.G. Chen, L.M. Cohen, W. Gu, P.T. Konkola, O. Mongrard, G.R. Ricker, Jr. and M.L. Schattenburg, *Constellation-X SXT Optics Team Meeting*, NASA Goddard Space Flight Center, Greenbelt, Maryland, August 7-8, 2001.
- “Microcomb/alignment bar design update,” R.K. Heilmann, C.G. Chen, O. Mongrard, M.L. Schattenburg and Y. Sun, *Constellation-X SXT Engineering Unit Technical Interchange Meeting*, NASA Goddard Space Flight Center, Greenbelt, Maryland, November 6, 2001.
- “High precision assembly and metrology of x-ray foil optics,” M.L. Schattenburg, O. Mongrard, N. Butler, C.G. Chen, R.K. Heilmann, P.T. Konkola, M. McGuirk, G. Monnelly, G.S. Pati, G.R. Ricker and L. Cohen, presented at the *Sixteenth Annual Meeting of the American Society for Precision Engineering*, Arlington, Virginia, November 10-15, 2001 (paper II-4).
- “Silicon microcombs for precision x-ray foil assembly,” Y. Sun, O. Mongrard, C. Chen, R.K. Heilmann, C. Forest, J. You, M. Spenko and M.L. Schattenburg, presented at the *Constellation X Mission Facility Science Team Meeting*, NASA Goddard Space Flight Center, Greenbelt, Maryland, November 15-16, 2001.
- “X-ray reflection grating update,” Y. Sun, O. Mongrard, C. Chen, R.K. Heilmann, C. Forest, J. You, M. Spenko and M.L. Schattenburg, presented at the *Constellation X Mission Facility Science Team Meeting*, NASA Goddard Space Flight Center, Greenbelt, Maryland, November 15-16, 2001.
- “Proposed off-plane reflection grating fabrication process,” M.L. Schattenburg and G.R. Ricker, presented at the *Constellation X Mission Facility Science Team Meeting*, NASA Goddard Space Flight Center, Greenbelt, Maryland, November 15-16, 2001.
- “The importance of nanotechnology and nanometrology for space

- instrumentation," M.L. Schattenburg, *Space Nano-technology Workshop, Tsukuba Space Center, National Space Development Agency of Japan, Tsukuba, Japan, November 27, 2001 (invited)*.
- "Advanced technology for future x-ray astronomy missions," M.L. Schattenburg, *Institute for Space and Astronautical Science, Sagamihara, Japan, November 28, 2001 (invited)*.
- "Space nanotechnology," M.L. Schattenburg, private briefing to the *Council for Science and Technology Policy, Japanese Cabinet Office, Tokyo, Japan, November 29, 2001 (invited)*.
- "MIT 2.75 PMD project: x-ray optics assembly truss," C. Forest, Y. Sun, M. Spenko, M.L. Schattenburg and A. Slocum, *MIT Precision Machine Design Class (2.75) Final Presentation, Cambridge, Massachusetts, December 12, 2001*.
- "MIT Space Nanotechnology Lab x-ray optics assembly truss," C. Forest, Y. Sun, M. Spenko, M.L. Schattenburg and A. Slocum, *Constellation-X SXT Engineering Unit Technical Interchange Meeting, NASA Goddard Space Flight Center, Greenbelt, Maryland, January 23, 2002*.
- "Nanometrology research at MIT," M.L. Schattenburg and H.I. Smith, *University of Central Florida, School of Optics/CREOL Seminar, Orlando, Florida, February 19, 2002 (invited)*.
- "Nanometrology research at MIT," M.L. Schattenburg and H.I. Smith, *International SEMATECH -- Metrology Council Meeting, Austin, Texas, February 26, 2002 (invited)*.
- "The critical role of metrology in nanotechnology," M.L. Schattenburg, *MIT Mechanical Engineering Department Seminar, Cambridge, Massachusetts, March 1, 2002 (invited)*.
- "Reflection Grating Spectrometer (RGS) progress report," M.L. Schattenburg and R.K. Heilmann, *Constellation X Mission Facility Science Team Meeting, Greenbelt, Maryland, May 1, 2002*.
- "Technology for a large-area reflection grating spectrometer on Constellation-X," S.M. Kahn, F. Paerels, A. Rasmussen, M.L. Schattenburg, G.R. Ricker, M.W. Bautz, J.P. Doty, G.Y. Prigozhin, J. Nousek, D. Burrows, J.E. Hill and W. Cash, *Constellation X Mission Facility Science Team Meeting, Greenbelt, Maryland, May 1, 2002*.
- "Thin Foil Optic," V. Guillaume, Internship Presentation, MIT Center for Space Research, Cambridge, Massachusetts, June 19, 2002.
- "Grating production methods," M.L. Schattenburg and R.K. Heilmann, *Constellation X-ray Mission Reflection Grating/CCD Team Technical Working Meeting, Cambridge, Massachusetts, July 3, 2002*.
- "Constellation-X spectroscopy x-ray telescope (SXT)," R. Petre, W.W. Zhang, D.A. Content, T. T. Saha, J. Stewart, J.H. Hair, D. Nguyen, W.A. Podgorski, W.R. Davis, Jr., M.D. Freeman, L.M. Cohen, M.L. Schattenburg, R.K. Heilmann, Y. Sun and C. Forest, abstract submitted to the *SPIE Conference on X-ray and Gamma-ray Telescopes and Instruments for Astronomy (AS18), Wailoloa, Hawaii, August 25-28, 2002 (paper 4851-50)*.

- “Constellation-X soft x-ray telescope assembly and alignment,” W.A. Podgorski, D.A. Content, J.H. Hair, R. Petre, T.T. Saha, M.L. Schattenburg, J. Stewart and W.W. Zhang, abstract submitted to the *SPIE Conference on X-ray and Gamma-ray Telescopes and Instruments for Astronomy (AS18)*, Wailoloa, Hawaii, August 25-28, 2002 (*paper 4851-57*).
- “Fabrication and assembly of in-plane reflection gratings for *Constellation-X*,” M.L. Schattenburg, C.G. Chen, C. Forest, R.K. Heilmann, P. Konkola, J. Przybylowski, Y. Sun, J. You, S.M. Kahn and D. Golini, abstract submitted to the *SPIE Conference on X-ray and Gamma-ray Telescopes and Instruments for Astronomy (AS18)*, Wailoloa, Hawaii, August 25-28, 2002 (*paper 4851-62*).
- “Constellation-X soft x-ray telescope segmented optic assembly and alignment implementation,” J.H. Hair, J. Stewart, R. Petre, W.W. Zhang, D.A. Content, T.T. Saha, W.A. Podgorski, P.E. Glenn, M.L. Schattenburg, R.K. Heilmann, Y. Sun and G. Nanan, abstract submitted to the *SPIE Conference on X-ray and Gamma-ray Telescopes and Instruments for Astronomy (AS18)*, Wailoloa, Hawaii, August 25-28, 2002 (*paper 4851-76*).
- “Advanced x-ray optics for x-ray astronomy,” M.L. Schattenburg, Space Research Institute (IKI) of Russian Academy of Sciences, Moscow, Russia, September 11, 2002 (*invited*). CANCELLED?
- “Precision microcomb design and fabrication for Constellation-X soft x-ray telescope segmented optic assembly,” Y. Sun, C.G. Chen, R.K. Heilmann, C. Forest, M. Spenko, P.T. Konkola, M. McGuirk, C. Joo and M.L. Schattenburg, presented at the *17th Annual Meeting of the American Society of Precision Engineering*, St. Louis, Missouri, October 20-25, 2002.
- “High precision assembly and metrology of x-ray foil optics,” C.R. Forest, Y. Sun, M. McGuirk, M.L. Schattenburg, M.J. Spenko and A.H. Slocum, presented at the *17th Annual Meeting of the American Society of Precision Engineering*, St. Louis, Missouri, October 20-25, 2002.

Master’s Thesis

Olivier Mongrard, *High Accuracy Foil Optics for X-ray Astronomy*, Master’s Thesis, MIT Department of Aeronautical and Astronautical Engineering, September 2001.

Patents

None